CLAIMS

What is claimed is:

1. A method for forming an ONO structure, comprising:

providing an oxide-nitride film on a surface of a substrate, the oxide-nitride film including a first oxide layer over the substrate and a silicon nitride layer over the first oxide layer;

patterning the oxide-nitride film to define bottom oxide and silicon nitride portions of an ONO stack on the substrate, the bottom oxide and silicon nitride portions having exposed sidewalls and the silicon nitride portion having an exposed surface; and

exposing the exposed sidewalls and the exposed surface to a rapid thermal oxidation in an ambient containing a radical oxidizing agent, to form an oxide layer on the exposed surface and sidewalls of the patterned silicon nitride portion and on the sidewalls of the patterned bottom oxide portion.

2. The method of claim 1 wherein the radical oxidizing agent comprises an oxygen radical.

3. The method of claim 1 wherein the radical oxidizing agent comprises $O^{\bullet}$.

4. The method of claim 1 wherein the exposing comprises heating the substrate to a selected temperature and exposing the exposed sidewalls and the exposed surface to a mixture of an oxygen-containing gas and a hydrogen-containing gas in a selected proportion at a selected pressure and for a selected time, whereby components of the oxygen-containing gas and the hydrogen-containing gas react to produce the radical oxidizing agent near the heated substrate.

5. The method of claim 4 wherein heating the substrate comprises heating the substrate to a temperature in a range about 700 °C to about 1300 °C.

6. The method of claim 4 wherein heating the substrate comprises heating the substrate to a temperature in a range about 900 °C to about 1150 °C.

7. The method of claim 4 wherein heating the substrate comprises heating the substrate to a temperature in a range about 850 °C to about 1000 °C.

8. The method of claim 1 wherein the exposing comprises heating the substrate to a selected temperature and exposing the exposed sidewalls and the exposed surface to a mixture of O_2 and H_2 in a selected proportion at a selected pressure and for a selected time, whereby components of the O_2 and H_2 react to produce $O^{\cdot}$ near the heated substrate.

9. The method of claim 8 wherein the exposing comprises heating the substrate to a temperature in a range about 700 °C to about 1300 °C, exposing the exposed sidewalls and the exposed surface to a mixture of O_2 and H_2 in a proportion in a range about 0.1% to about 40% (H_2 / H_2 + O_2) at a pressure in a range about 1 torr to about 20 torr for a time in a range about 1 to 1000 seconds.

10. The method of claim 9 wherein the heating comprises heating the substrate to a temperature in a range about 900 °C to about 1150 °C.

11. The method of claim 9 wherein heating the substrate comprises heating the substrate to a temperature in a range about 850 °C to about 1000 °C.

12. The method of claim 9 wherein the exposing comprises flowing over the heated substrate a mixture of O_2 and H_2 in a proportion in a range about 5% to about 33% (H_2 / H_2 + O_2).

13. The method of claim 9 wherein the exposing comprises flowing over the heated substrate a mixture of O_2 and H_2 in a proportion in a range about 1:19 to about 1:2 (H_2 : O_2).

14. The method of claim 9 wherein the exposing comprises flowing the mixture of O_2 and H_2 over the heated substrate for a time in a range about 10 seconds to about 500 seconds.

15. The method of claim 9 wherein the exposing comprises flowing the mixture of O_2 and H_2 over the heated substrate for a time in a range about 30 seconds to about 300 seconds.

16. The method of claim 1 wherein the exposing comprises heating the substrate in a furnace and flowing into the furnace a mixture of O_2 and H_2 in a selected proportion at a selected pressure and for a selected time, whereby components of the O_2 and H_2 react to produce $O^{\cdot}$ near the heated substrate.

17. The method of claim 16 wherein flowing the mixture of O_2 and H_2 further comprises flowing a carrier gas.

18. The method of claim 17 wherein flowing the mixture of O_2 and H_2 further comprises flowing N_2 as a carrier gas.

19. The method of claim 16 wherein flowing the mixture of O_2 and H_2 in a selected proportion comprises flowing the O_2 and H_2 at selected proportional flow rates.

20. The method of claim 19 wherein flowing the mixture of O_2 and H_2 further comprises flowing N_2 as a carrier gas at a selected flow rate.

21. The method of claim 19 wherein flowing the O_2 and H_2 comprises flowing O_2 and H_2 at a combined flow rate in a range about 1 to about 40 slm.

22. The method of claim 20 wherein flowing the O_2 and H_2 comprises flowing O_2 and H_2 at a combined flow rate in a range about 1 to about 40 slm, and flowing N_2 comprises flowing N_2 at a flow rate up to about 50 slm.

23. A method for manufacturing a semiconductor device having an ONO structure, comprising:

providing an oxide-nitride film on a surface of a substrate, the substrate having first and second regions defined by an isolation, the oxide-nitride film including a first silicon oxide layer over the substrate and a silicon nitride layer over the first silicon oxide layer;

patterning the oxide-nitride film to expose a surface of the substrate in the second region and to define bottom oxide and silicon nitride portions of an ONO stack in the first region of the substrate, the bottom oxide portion and silicon nitride portions having exposed sidewalls and the silicon nitride portion having an exposed surface; and

exposing the exposed sidewalls and the exposed surface to a radical oxidizing agent while the substrate is at a temperature in a range about 700 °C to about 1200 °C, to form concurrently a second oxide layer on the exposed surface and sidewalls of the patterned silicon nitride portion and a gate oxide layer on the substrate surface in the second region; and

forming a conductive layer over the second oxide layer and over the gate oxide layer.

24. The method of claim 23 wherein the radical oxidizing agent comprises an oxygen radical.

25. The method of claim 23 wherein the radical oxidizing agent comprises $O^{\bullet}$.

26. The method of claim 23 wherein the exposing comprises heating the substrate to the temperature in the temperature range and exposing the exposed sidewalls and the exposed surface to a mixture of an oxygen-containing gas and a hydrogen-containing gas in a selected proportion at a selected pressure and for a selected time, whereby components of the oxygen-containing gas and the hydrogen-containing gas react to produce the radical oxidizing agent near the heated substrate.

27. The method of claim 26 wherein heating the substrate comprises heating the substrate to a temperature in a range about 900 °C to about 1150 °C.

28. The method of claim 26 wherein heating the substrate comprises heating the substrate to a temperature in a range about 850 °C to about 1000 °C.

29. The method of claim 23 wherein the exposing comprises heating the substrate to the temperature in the temperature range and exposing the exposed sidewalls and the exposed surface to a mixture of O_2 and H_2 in a selected proportion at a selected pressure and for a selected time, whereby components of the O_2 and H_2 react to produce $O^{\bullet}$ near the heated substrate.

30. The method of claim 29 wherein the exposing comprises heating the substrate to a temperature in temperature range, exposing the exposed sidewalls and the exposed surface to a mixture of O_2 and H_2 in a proportion in a range about 0.1% to about 40% (H_2 / H_2 + O_2) at a pressure in a range about 1 torr to about 20 torr for a time in a range about 1 to 1000 seconds.

31. The method of claim 30 wherein the heating comprises heating the substrate to a temperature in a range about 900 °C to about 1150 °C.

32. The method of claim 30 wherein heating the substrate comprises heating the substrate to a temperature in a range about 850 °C to about 1000 °C.

33. The method of claim 30 wherein the exposing comprises flowing over the heated substrate a mixture of O_2 and H_2 in a proportion in a range about 5% to about 33% (H_2 / H_2 + O_2).

34. The method of claim 30 wherein the exposing comprises flowing over the heated substrate a mixture of O_2 and H_2 in a proportion in a range about 1:19 to about 1:2 ($H_2 : O_2$).

35. The method of claim 30 wherein the exposing comprises flowing the mixture of O_2 and H_2 over the heated substrate for a time in a range about 10 seconds to about 500 seconds.

36. The method of claim 30 wherein the exposing comprises flowing the mixture of O_2 and H_2 over the heated substrate for a time in a range about 30 seconds to about 300 seconds.

37. The method of claim 23 wherein the exposing comprises heating the substrate in a furnace and flowing into the furnace a mixture of O_2 and H_2 in a selected proportion at a selected pressure and for a selected time, whereby components of the O_2 and H_2 react to produce $O^{\cdot}$ near the heated substrate.

38. The method of claim 37 wherein flowing the mixture of O_2 and H_2 further comprises flowing a carrier gas.

39. The method of claim 38 wherein flowing the mixture of O_2 and H_2 further comprises flowing N_2 as a carrier gas.

40. The method of claim 37 wherein flowing the mixture of O_2 and H_2 in a selected proportion comprises flowing the O_2 and H_2 at selected proportional flow rates.

41. The method of claim 40 wherein flowing the mixture of O_2 and H_2 further comprises flowing N_2 as a carrier gas at a selected flow rate.

42. The method of claim 40 wherein flowing the O_2 and H_2 comprises flowing O_2 and H_2 at a combined flow rate in a range about 1 to about 40 slm.

43. The method of claim 41 wherein flowing the O_2 and H_2 comprises flowing O_2 and H_2 at a combined flow rate in a range about 1 to about 40 slm, and flowing N_2 comprises flowing N_2 at a flow rate up to about 50 slm.

44. The method of claim 23 wherein a ratio of thicknesses of the formed second oxide layer and the formed gate oxide layer is in a range about 0.6:1 to about 0.8:1.

45. The method of claim 23 wherein the exposing comprises heating the substrate in a furnace and generating the radical oxidizing agent within the furnace while holding the substrate at a temperature in the temperature range for a time in a range about 10 seconds to about 500 seconds.

46. The method of claim 23 wherein the exposing comprises heating the substrate in a furnace and generating the radical oxidizing agent within the furnace while holding the substrate at a temperature in the temperature range for a time in a range about 30 seconds to about 300 seconds.

47. A method for manufacturing a memory device having an ONO structure, comprising:

providing an oxide-nitride film on a surface of a substrate, the substrate having first and second regions defined by an isolation, the oxide-nitride film including a first silicon oxide layer over the substrate and a silicon nitride layer over the first silicon oxide layer;

patterning the oxide-nitride film to expose a surface of the substrate in the second region and to define bottom oxide and silicon nitride portions of an ONO stack in the first region of the substrate, the bottom oxide portion and silicon nitride portions having exposed sidewalls and the silicon nitride portion having an exposed surface; and

exposing the exposed sidewalls and the exposed surface to a radical oxidizing agent while the substrate is at a temperature in a range about 700 °C to about 1200 °C, to form concurrently a second oxide layer on the exposed surface and sidewalls of the patterned silicon nitride portion and a gate oxide layer on the substrate surface in the second region; and

forming a conductive layer over the second oxide layer and over the gate oxide layer.

48. The method of claim 47 wherein the radical oxidizing agent comprises an oxygen radical.

49. The method of claim 47 wherein the radical oxidizing agent comprises $O^{\bullet}$.

50. The method of claim 47 wherein the exposing comprises heating the substrate to the temperature in the temperature range and exposing the exposed sidewalls and the exposed surface to a mixture of an oxygen-containing gas and a hydrogen-containing gas in a selected proportion at a selected pressure and for a selected time, whereby components of the oxygen-containing gas and the hydrogen-containing gas react to produce the radical oxidizing agent near the heated substrate.

51. The method of claim 50 wherein heating the substrate comprises heating the substrate to a temperature in a range about 900 °C to about 1150 °C.

52. The method of claim 50 wherein heating the substrate comprises heating the substrate to a temperature in a range about 850 °C to about 1000 °C.

53. The method of claim 47 wherein the exposing comprises heating the substrate to the temperature in the temperature range and exposing the exposed sidewalls and the exposed surface to a mixture of O_2 and H_2 in a selected proportion at a selected pressure and for a selected time, whereby components of the O_2 and H_2 react to produce $O^{\cdot}$ near the heated substrate.

54. The method of claim 53 wherein the exposing comprises heating the substrate to a temperature in temperature range, exposing the exposed sidewalls and the exposed surface to a mixture of O_2 and H_2 in a proportion in a range about 0.1% to about 40% (H_2 / H_2 + O_2) at a pressure in a range about 1 torr to about 20 torr for a time in a range about 1 to 1000 seconds.

55. The method of claim 54 wherein the heating comprises heating the substrate to a temperature in a range about 900 °C to about 1150 °C.

56. The method of claim 54 wherein heating the substrate comprises heating the substrate to a temperature in a range about 850 °C to about 1000 °C.

57. The method of claim 54 wherein the exposing comprises flowing over the heated substrate a mixture of O_2 and H_2 in a proportion in a range about 5% to about 33% (H_2 / H_2 + O_2).

58. The method of claim 54 wherein the exposing comprises flowing over the heated substrate a mixture of O_2 and H_2 in a proportion in a range about 1:19 to about 1:2 (H_2 : O_2).

59. The method of claim 54 wherein the exposing comprises flowing the mixture of O_2 and H_2 over the heated substrate for a time in a range about 10 seconds to about 500 seconds.

60. The method of claim 54 wherein the exposing comprises flowing the mixture of O_2 and H_2 over the heated substrate for a time in a range about 30 seconds to about 300 seconds.

61. The method of claim 47 wherein the exposing comprises heating the substrate in a furnace and flowing into the furnace a mixture of O_2 and H_2 in a selected proportion at a selected pressure and for a selected time, whereby components of the O_2 and H_2 react to produce O^{*} near the heated substrate.

62. The method of claim 61 wherein flowing the mixture of O_2 and H_2 further comprises flowing a carrier gas.

63. The method of claim 62 wherein flowing the mixture of O_2 and H_2 further comprises flowing N_2 as a carrier gas.

64. The method of claim 61 wherein flowing the mixture of O_2 and H_2 in a selected proportion comprises flowing the O_2 and H_2 at selected proportional flow rates.

65. The method of claim 64 wherein flowing the mixture of O_2 and H_2 further comprises flowing N_2 as a carrier gas at a selected flow rate.

66. The method of claim 64 wherein flowing the O_2 and H_2 comprises flowing O_2 and H_2 at a combined flow rate in a range about 1 to about 40 slm.

67. The method of claim 65 wherein flowing the O_2 and H_2 comprises flowing O_2 and H_2 at a combined flow rate in a range about 1 to about 40 slm, and flowing N_2 comprises flowing N_2 at a flow rate up to about 50 slm.

68. The method of claim 47 wherein a ratio of thicknesses of the formed second oxide layer and the formed gate oxide layer is in a range about 0.6:1 to about 0.8:1.

69. The method of claim 47 wherein the exposing comprises heating the substrate in a furnace and generating the radical oxidizing agent within the furnace while holding the substrate at a temperature in the temperature range for a time in a range about 10 seconds to about 500 seconds.

70. The method of claim 47 wherein the exposing comprises heating the substrate in a furnace and generating the radical oxidizing agent within the furnace while holding the substrate at a temperature in the temperature range for a time in a range about 30 seconds to about 300 seconds.

71. A semiconductor device having a silicon oxide/silicon nitride/silicon oxide structure, comprising

a first silicon oxide layer over a substrate;

a silicon nitride layer over a portion of the first silicon oxide layer;

a second silicon oxide layer fully covering the silicon nitride layer and contacting the first silicon oxide layer; and

a gate conducting layer over the silicon oxide layer.

72. A memory cell having a silicon oxide/silicon nitride/silicon oxide structure, comprising

a buried drain and a buried source within a substrate;

a buried drain oxide layer over the buried drain and a buried source oxide layer over the buried source;

a first silicon oxide layer covering a region of the substrate located between the buried drain and the buried source and covering a portion of the buried drain oxide layer and a portion of the buried source oxide layer;

a silicon nitride layer covering a portion of the first silicon oxide layer;

a second silicon oxide layer fully covering the silicon nitride layer and contacting the first silicon oxide layer;

and a gate conducting layer over the second silicon oxide layer.

73. A memory cell having a silicon oxide/silicon nitride/silicon oxide structure in a read-only memory, comprising

a buried drain and a buried source located within a substrate;

a buried drain oxide layer over the buried drain and a buried source oxide layer over the buried source;

a first silicon oxide layer covering a region of the substrate located between the buried drain and the buried source and covering a portion of the buried drain oxide layer and a portion of the buried source oxide layer;

a silicon nitride layer covering a portion of the first silicon oxide layer;

a second silicon oxide layer fully covering the silicon nitride layer and contacting the first silicon oxide layer; and

a gate conducting layer over the second silicon oxide layer.